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ACCELERATED TESTING FOR STUDYING PAVEMENT DESIGN AND PERFORMANCE (FY 99)

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16 Abstract

The objectives of the project described in this report are to perform the experimental work and associated data acquisition/data processing for the research study entitled “Rut Resistance of Superpave Mixtures Containing River Sands.” The goal of the research is to compare the rut-resistance of Superpave mixtures in which different ratios of river sands have been used. The work described in this report deals with the experimental aspects of the research study. This mainly entails the applications of realistic wheel/axle load cycles to large-scale full-depth pavement slabs in controlled thermal conditions. The experiment was conducted at the Kansas Accelerated Testing Laboratory at Kansas State University. The experimental work also includes monitoring and measuring the degree of rutting of the asphalt surface and recording the states of strains, soil pressure, and temperature gradients in and below the pavement slabs being tested.

Four mixes were tested in this experiment. These are denoted as follows:

Mix 1: a standard KDOT Marshall-type mix, BM-2C
Mix 2: a Superpave mix SM-2A with 20% sand
Mix 3: a Superpave mix SM-2A with 30% sand
Mix 4: a Superpave mix SM-2A with 15% sand

By comparing the final rutting at the end of 80,000 load repetitions of a dual tandem axle of 150 kN (34 kips), it was observed that, except for the mix with 30% sand, Superpave mixes show less rutting less than the Marshall mix. The best performing mix of all the four sections tested is Mix 2, indicating that 20% ratio is the optimum sand content in these Superpave mixes. On the other hand, 30% ratio is the worst sand content and resulted in the most rutting (unacceptable, more than one inch).

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Final Report on

Accelerated Testing for Studying Pavement Design and Performance (FY 99)

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Project Monitor:
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July 2000

Abstract

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Acknowledgments

The research experiment described in this report was selected, designed, and monitored by the members of the Midwest States Accelerated Testing Pooled Fund Technical Committee. The committee includes Mr. Andrew Gisi, Kansas Department of Transportation (KDOT), Chair, Mr. George Woolstrum, Nebraska Department of Roads (NDOR), Mr. Tom Keith, Missouri Department of Transportation (MDOT), and Mr. Mark Dunn (Iowa DOT). Their help, input, and support are acknowledged. The efforts of Mr. Richard McReynolds (KDOT) in administrating both the contract and the Technical Committee activity are appreciated.

The research idea of varying the river sand ratio in Superpave mixes was initially proposed by Dr. Mustaque Hossain, Associate Professor of Civil Engineering at KSU, in consultation with Mr. Glenn Fager from KDOT, as a K-TRAN pre-proposal. Consequently, the strain gauges, pressure cells, and thermocouples associated with this research experiment were purchased with funds from the K-TRAN:KSU-98-2 project entitled “Pilot Instrumentation of a Superpave Test Section at the Kansas Accelerated Testing Laboratory.” Dr. Hossain was the principal investigator and Mr. Zhong Wu was the graduate student for that project. Mr. Fager is also commended for designing the Superpave mixes, coordinating the placement of the test sections with the highway construction projects, and overseeing the base and pavement construction. The members of the KDOT Falling Weight Deflectometer (FWD) crew are commended for diligently conducting the periodic FWD tests on the pavement sections.

The authors would like to acknowledge the rest of the Kansas Accelerated Testing Lab team who participated in this project: Dr. Stuart Swartz, professor of Civil Engineering; Dr. Vijayanath Bhuvanagiri, post-doctorate research associate; and Mr. Paul Lewis, Research Technologist at the ATL. The following students have worked at the ATL throughout the duration of this experiments: Jenny Chin, Jason Dewald, and Jason Hoy. Mr. Jeffrey Davies helped with data collection, results classification, and graphics generation. The dedication of the research team is acknowledged.

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1.0 INTRODUCTION

1.1 Report Organization

This manuscript is the final report that describes the research project conducted under KDOT Contract C119, “Accelerated Testing for Studying Pavement Design and Performance - FY 99" (KSU Account 5-33961). This contract is funded by the Midwest States Accelerated Testing Pooled Fund Program. States participating in this program are Iowa, Kansas, Missouri, and Nebraska.

The purpose of the project is to conduct the experiment selected by the Midwest States Accelerated Testing Pooled Funds Technical Committee for Fiscal Year 1999 (FY-99). During its meeting on April 28, 1998 in St. Joseph, Missouri, the Committee selected the then-called “Kansas Two” experiment as the main activity to be conducted during Fiscal Year 1999. The title of the experiment selected was “Rut Resistance of Superpave Mixtures Containing River Sands.”

This experiment is the seventh experiment conducted at the Kansas Accelerated Testing Lab (K-ATL) and is therefore identified as ATL-Exp #7. The first two experiments, ATL-Exp #1 and #2, were reported in “Development of an Accelerated Testing Laboratory for Highway Research in Kansas [1],” and ATL-Exp #3 through #6 were reported in “Accelerated Testing for Studying Pavement Design and Performance - FY97-98 [2].”

This report describes the following aspects of ATL-Exp #7:

1. The test setup and testing strategies followed.
2. The pavement structure and material used for subbase and pavement construction.
3. The executed monitoring plan.
4. A description of the experiment: This includes the experimental work performed in terms of the total number of cycles applied to each specimen, testing conditions (loads, temperatures, etc.), and the testing activity and corresponding time schedule.
5. A summary of the data collected, results from instrumentation, and processed data in form of rutting profiles, variations (curves/histograms) of measured quantities as a function of load cycles applied, and comparison of the responses of the different pavement mixes.
6. The preliminary conclusions that may be drawn from the obtained results and observed performance.

The remainder of this chapter is a general overview of the project. Chapter 2 provides a background on the theory of rutting, and the types of instrumentation used in this project to evaluate rutting and other related pavement performance. Chapter 3 is a brief description of the testing facility with special emphasis on the particular features used in this experiment. This includes the lab space and test pits, test frame, wheel load assembly, and the surface radiant heating system. Chapter 4 gives a detailed description of the test experiment including the mix types and pavement construction process, loading conditions, heat application and temperature setting, sensor installation and data acquisition, and the executed performance monitoring plan. Finally, Chapter 5 discusses the test results, pavement performance, and conclusions.

1.2 Project Overview

The objectives of the project described in this report are to perform the experimental work and associated data acquisition/data processing for the research study entitled "Rut Resistance of Superpave Mixtures Containing River Sands." The goal of the research is to compare the rut-resistance of Superpave mixtures in which different ratios of river sands have been used. The work described in this report deals with the experimental aspects of the research study. This mainly entails the applications of realistic wheel/axle load cycles to large-scale full-depth pavement slabs in controlled thermal conditions. The experiment was conducted at the Kansas Accelerated Testing Laboratory of Kansas State University. The experimental work also includes monitoring and measuring the degree of rutting of the asphalt surface, and recording the states of strains, soil pressure, and temperature gradients in and below the pavement slabs being tested.

This experimental investigation, when compared with the performance of similar mixes used in control sections on in-service highways, and supplemented with further analytical studies, can help the Kansas Department of Transportation (KDOT) and other state agencies establish or modify existing special provisions for Superpave mixtures. It may also lead to standard guidelines for instrumentation of in-service highway pavement in the States participating in the Pooled Fund Program. These would include numerical modeling, evaluation of mechanistic responses, analysis of Falling Weight Deflectometer (FWD) data, and comparative studies with other research in the United States and abroad. This may necessitate further experimental investigations, and possibly additional testing at the K-ATL.

The instrumentation (strain gauges, pressure cells, and thermocouples) associated with this research experiment were purchased with funds from a separate project entitled "Pilot Instrumentation of a Superpave Test Section at the Kansas Accelerated Testing Laboratory [3]." This project was funded by KDOT as K-TRAN: KSU-98-2. Detailed data analysis and correlation of the mechanistic responses with the pavement performance in terms of fatigue damage, rutting and/or serviceability and Superpave mixture composition have been proposed in the K-TRAN project. Research implementation in the form of revised special provisions for the Superpave mixture in Kansas, as far as natural (river) sand content is concerned, and full-scale in-service Superpave pavement instrumentation in Kansas may result from that study [3]. A preliminary analysis of the data, and the comparison of Falling Weight Deflectometer (FWD) results with estimated values obtained from a multi-layer elastic analysis, are presented in “Instrumentation of the Superpave Test Sections at the Kansas Accelerated Testing Laboratory [4].”

The effort outlined in this report encompasses the application of truck axle loads in a controlled environment as dictated by the physical requirements for this experiment. The load cycles and surface temperature were applied according to a tight and detailed monitoring plan in order to obtain the necessary data on tensile strains, soil pressure, rut depth, pavement density, and surface profile. The monitoring plan is discussed in Section 4.5.

Four asphalt concrete mixes were tested in this experiment. One was a standard KDOT Marshall-type mix (BM-2C) and the other three were Superpave mixes (SM-2A) each with a different sand content (15%, 20%, and 30%). All four sections were placed together at the start of the experiment. The material placed at the K-ATL came from batches used in a construction project on Interstate 70 near Topeka. The same contractor working on the construction project was asked to bring material (trucks) to the ATL facility. Testing the same pavement mixes as those that were being placed on portions of the actual highway system can allow KDOT and future research studies to compare laboratory and field performances.

2.0 BACKGROUND

2.1 Theory For Rutting

Asphalt concrete mixtures subjected to repeated loads exhibit elastic, plastic, visco-elastic, and visco-plastic responses. Permanent deformation is cumulative under repeated loading and is mostly attributed to plastic properties. The following creep rate model is commonly used to characterize the permanent deformation:

$$\frac{d}{dt} \quad A \;\; {}^{n} t^{m} \qquad \textbf{(1)}$$

where $\in$ is the creep deformation, σ is the Mises equivalent stress, *t* is the total time, and *A, m,* and *n* are parameters related to material properties. In-service pavement rutting is affected by several factors as shown in Figure 2.1.

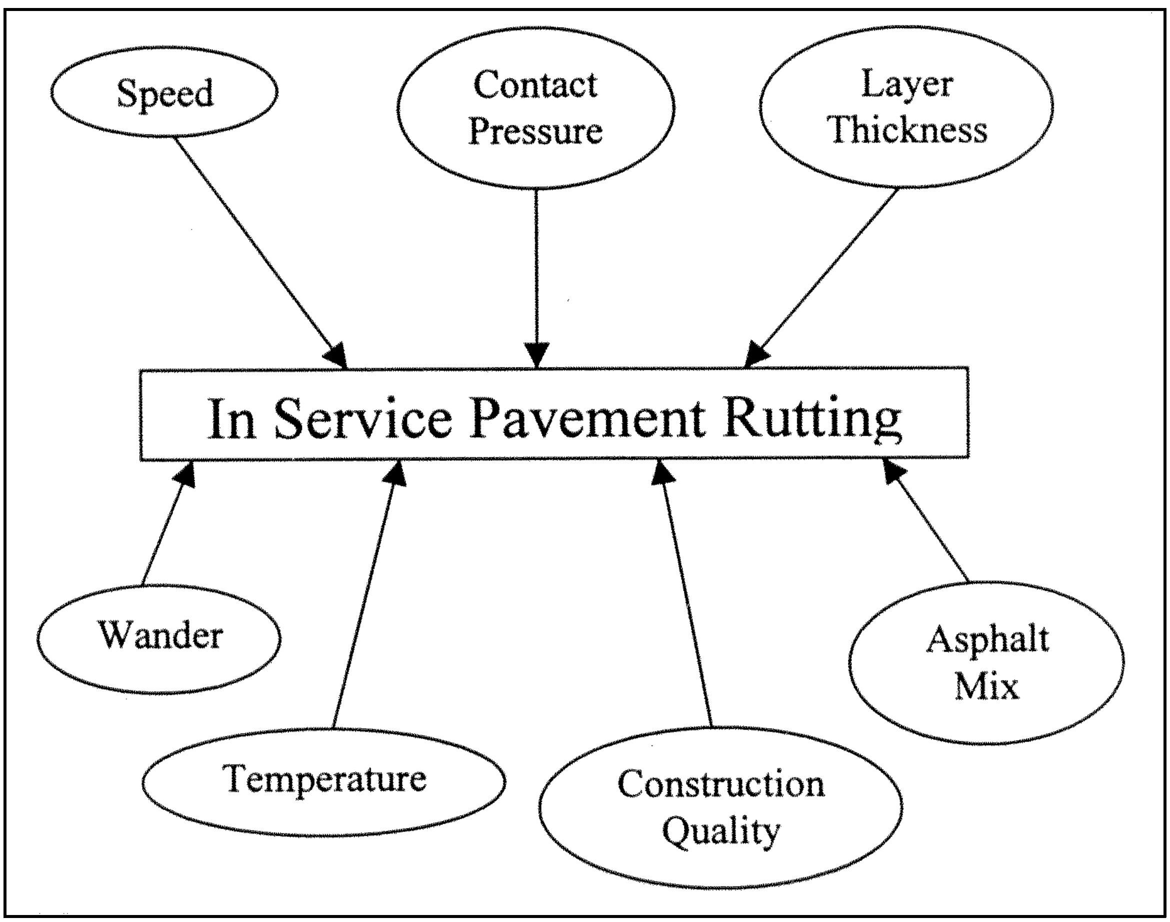

Figure 2.1 Factors Affecting Rutting [5]

Over the past few years, continuing research at Purdue University identified factors that have the most impact on rutting [5]. Based on the creep model of Equation 1, an analysis was conducted using the finite element software ABAQUS to study the effect of the three main factors, which are:

1. Vehicle speed
2. Tire contact pressure, and
3. Lateral wheel wander.

The first two factors can be directly represented in the creep model as time and normal pressure. Lateral wander is accounted for in the simulation of load sequence and load distribution. The other factors namely temperature, asphalt mixture and construction quality are determined experimentally and are inherent in the values of the material constants in the creep model. Layer thickness is accounted for in the pavement geometry and structure. Test results for rutting are shown in Figure 2.2. Experimental data from accelerated pavement testing were used to calibrate the creep model and compare measured and predicted rutting.

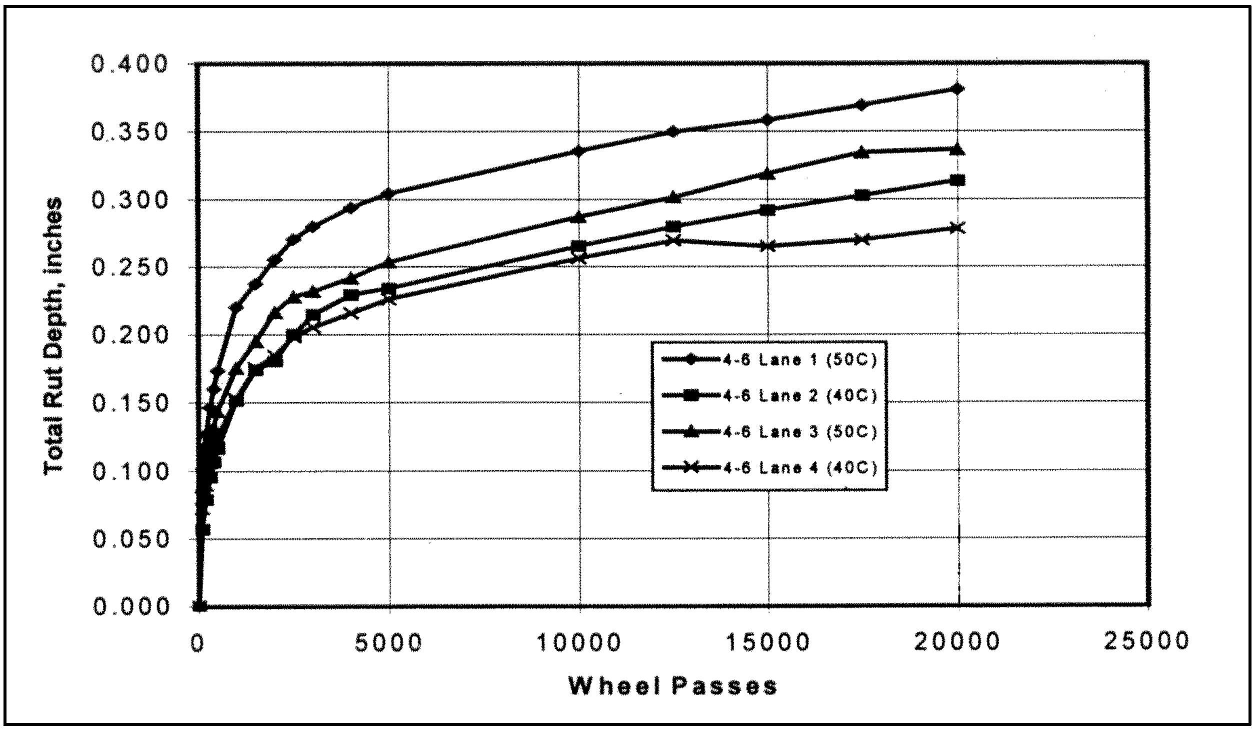

Figure 2.2 Rutting in Accelerated Testing Experiments

Good agreement between the measured and predicted rutting was obtained up to 5000 wheel passes. Effects of vehicle speed on rut depth are shown in Figure 2.3. Results of tests at 8 km/h (5 mph) can be extrapolated to higher traffic speed.

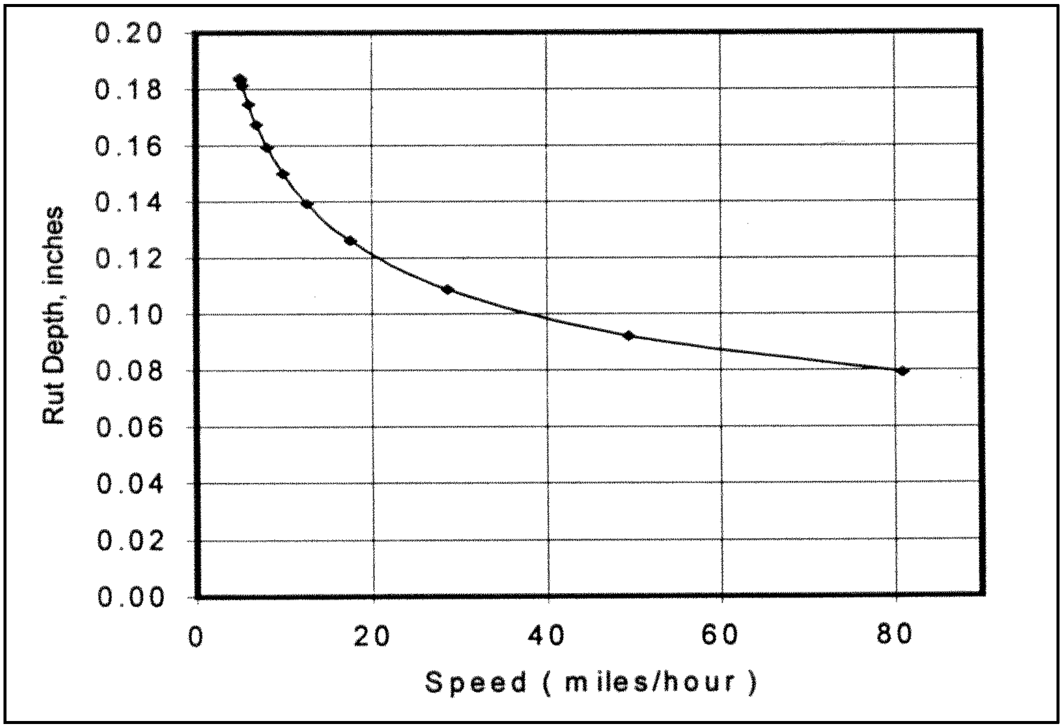

Figure 2.3 Effect of Vehicle Speed on Rutting

The effect of tire pressure is shown in Figure 2.4. The gross contact pressure was computed based on wheel load and measured gross tire print area. The gross tire contact pressure was found to be approximately equal to the tire pressure. Therefore, rutting at tire pressure of 621 kPa (90 psi) can be extrapolated to other levels of pressure.

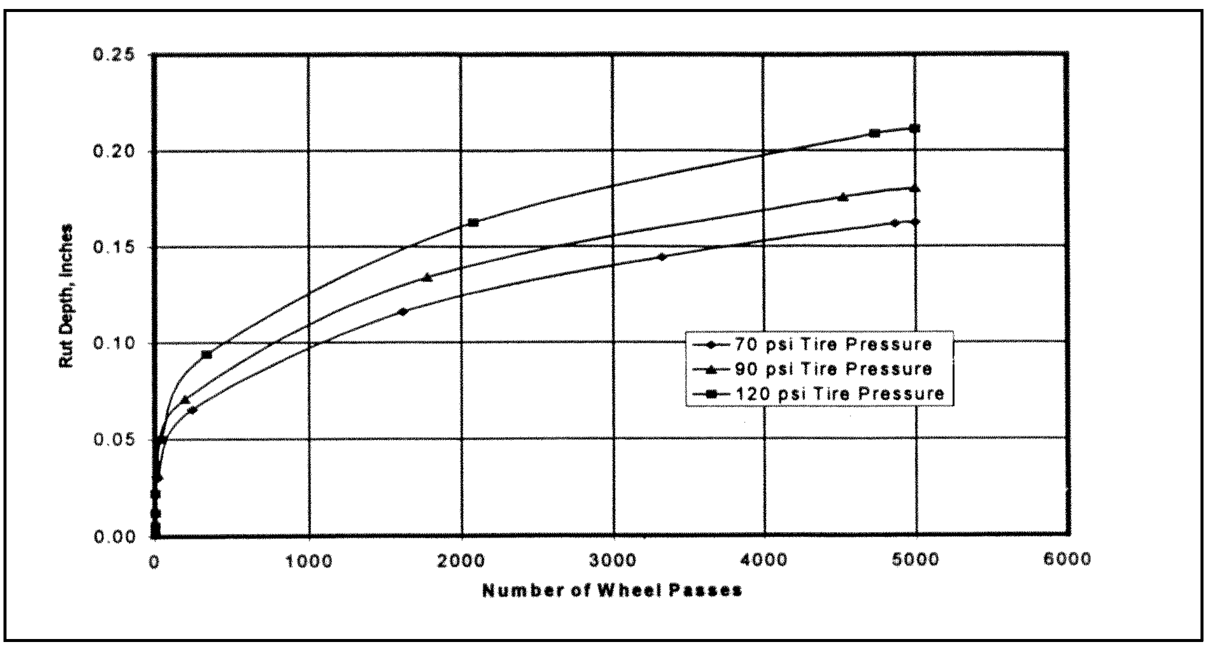

Figure 2.4 Effect of Tire Pressure on Rutting

Of particular importance to accelerated testing is the effect of lateral wheel wander. Because the testing machine at the K-ATL was not designed to include automated lateral wander, it would be preferable to avoid such a test procedure. Although simulated wheel wander has been done previously at the K-ATL as shown in Figure 2.5, it required quite a deal of manual labor.

For each 10,000 repetitions:

Displ (ft)	-1.5	-1	-0.5	0	0.5	1	1.5	**Sum =**
No. Reps.	712	1,316	1,899	2,146	1,899	1,316	712	**10,000**

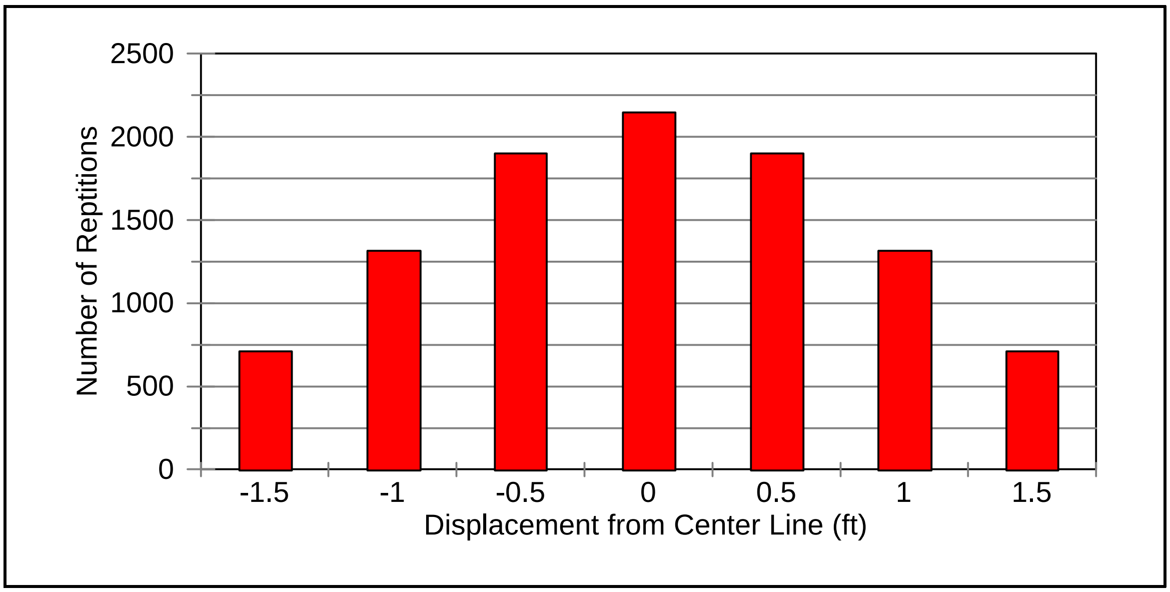

Figure 2.5 Simulated Wheel Wander at the K-ATL

Every so many cycles according to the chart shown in Figure 2.5, the test frame had to be released at the end-anchors, raised off the floor, and moved laterally to simulate a normal distribution with a discrete number of intervals. Heaters and other instruments had to be moved accordingly. This resulted in a significant increase in the testing operation time. However, tests at Purdue University have established a direct correlation between rut depth and wheel wander as shown in Figure 2.6.

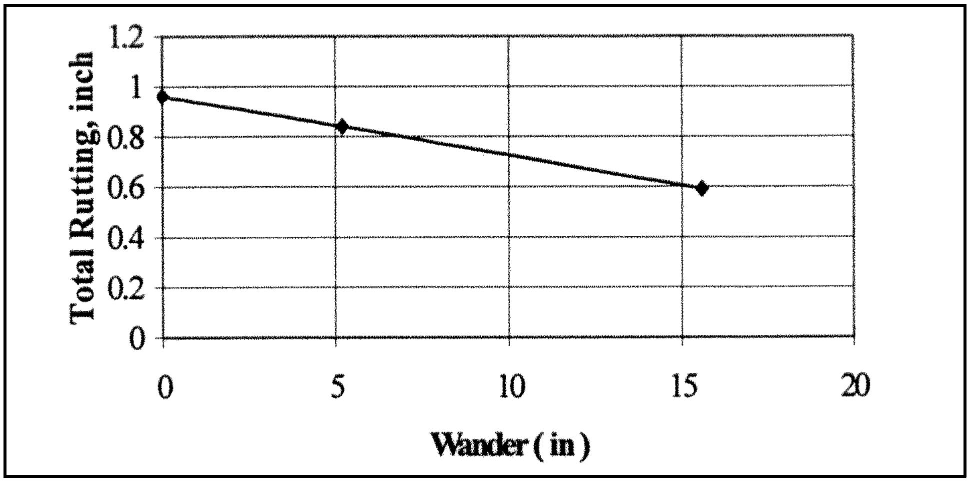

Figure 2.6 Effect of Wander on Rutting [5]

The effect of traffic with wander is to distribute load over a certain width of the pavement. Consequently loading time of any given wheel path is reduced. On the other hand, loads are applied where there would otherwise be a heave formed by the fixed path traffic, and such area is rather compacted and flattened. White and Hua predicted transverse surface profiles for different values of wander and conducted a number of tests which showed that predicted (computed) and measured results were in excellent agreement [5]. Figure 2.7 shows rutting under wheel path with and without wander.

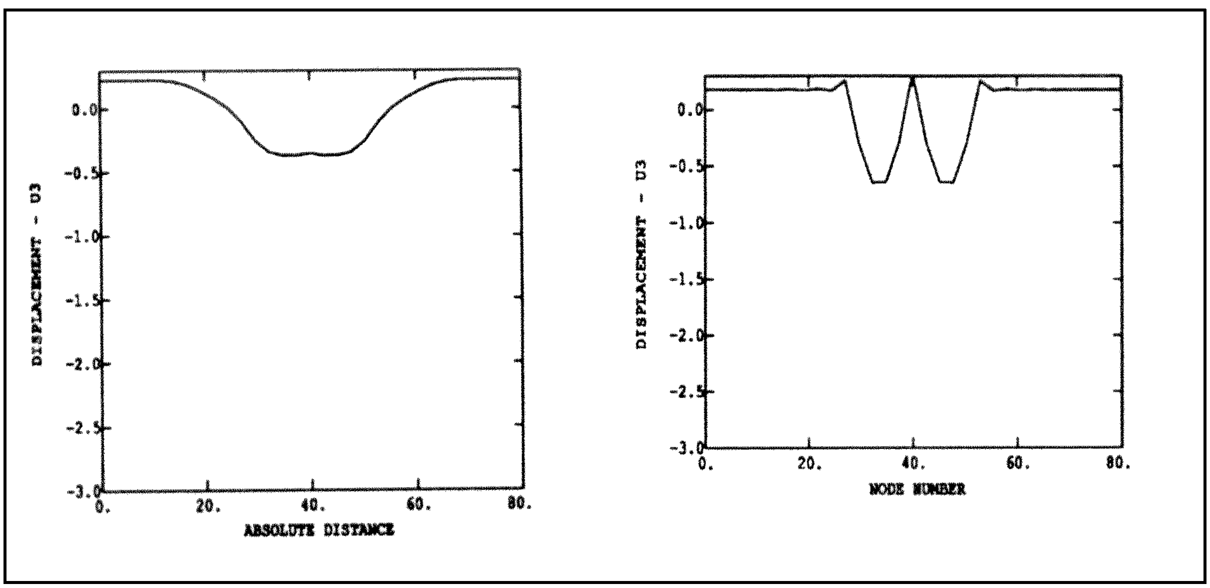

Figure 2.7 Rutting with: (a) 15 in. Wander, (b) Fixed Path (zero wander)

Subsequent personal communication with Dr. White confirmed testing with lateral wheel wander is not necessary when effects of other parameters such as asphalt mixture or temperature and load effects are the primary objectives of the study.

The tests performed at the K-ATL and described in this report applied loads only in a fixed wheel path. Other complementary research studies are being conducted in Indiana and elsewhere that will study different aspects of rutting. For instance, a National Pooled Fund study is underway at Purdue University to validate Superpave mixture criteria, and therefore the effect of asphalt mix on rutting.

2.2 Instrumentation

The following sensors were to be placed and monitored during the experiment (in the *test sections* only):

1. Strain Gauges (Dynatest PAST-2AC),
2. Dynamic Soil Pressure Cells (Geokon), and
3. Thermocouples (fabricated in-house at KSU).

These sensors were purchased using funds from the K-TRAN instrumentation project [3]. The number of sensors is specified in that project. These types of sensors have been used previously at the K-ATL and were successfully installed according to the manufacturer's guidelines and following procedures recommended by the MnRoad research program [6,7].

Data from similar strain gauges were observed and digitally recorded by K-ATL personnel during the FY-98 Accelerated Testing project. Thermocouple data were observed and digitally recorded during the FY-97 project. Response traces similar to those reported by other experimental researchers [8,9] and shown in Figures 2.8 and 2.9 were obtained at the K-ATL.

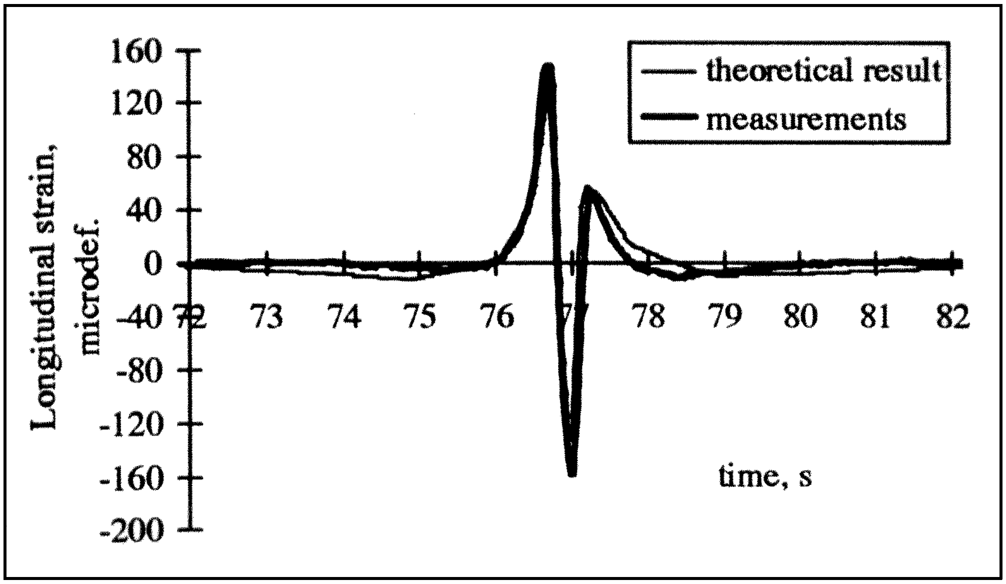

Figure 2.8 Longitudinal Strains from Accelerated testing Reported by Heck, *et al.* [8]

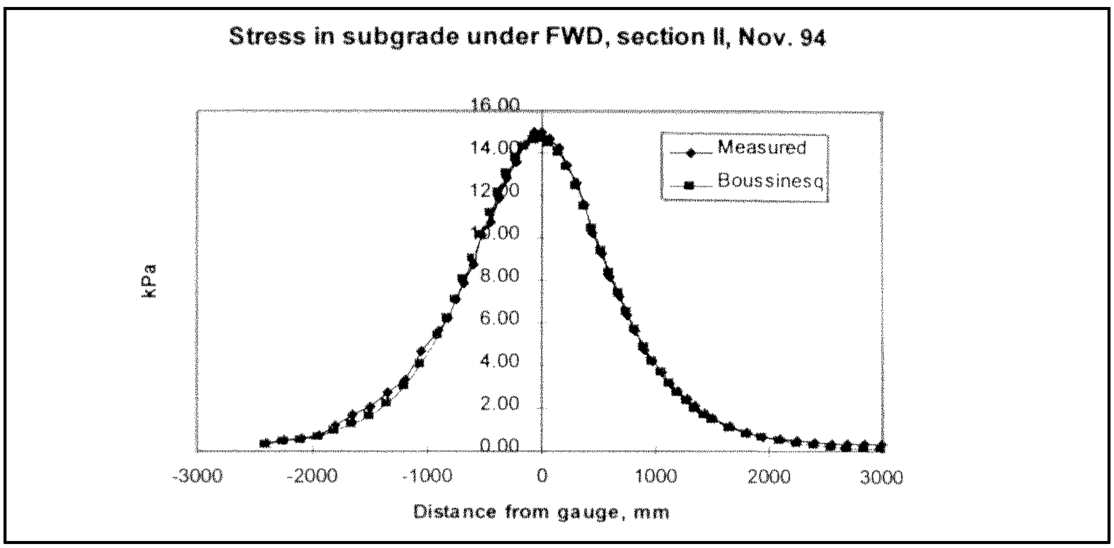

Figure 2.9 Influence Line for one Soil Pressure Cell Reported by Ullidtz & Ekdahl [9]

The sensors were installed by K-ATL personnel. Data was collected using the existing data acquisition system developed at the K-ATL through previous research contracts. The hardware consists of several terminal blocks on a number of corresponding SCXII modules mounted on instrumentation chassis. Data acquisition boards are installed in PC computers with Pentium processors. The software consist of the LabView package of which the Department of Civil Engineering at KSU has a license for 10 users. All hardware and software are products of National Instruments, Inc.

Additional boards and computer upgrades were acquired by the K-TRAN project ([4], p. 13). This is necessary to be able to record strain and pressure data simultaneously and to the extent proposed in the instrumentation project as described in Tasks 4 and 5 ([3], p. 14). Modifications to the previously developed computer programs (or VI's, standing for Virtual Instruments) were made as part of both this and the K-TRAN activities.

2.3 Transverse Rut Measuring Device

When studying rutting of asphalt pavement, in order to obtain accurate transverse profiles such as those shown in Figure 2.7, a better device needs to be used rather than relying on the Face dipstick apparatus. The dipstick gives readings every 305 mm (12 in.), and unless several passes are made, many of the heaves and valleys will be missed. Readings at much smaller intervals along the width of the pavement section are needed, such as every 13 mm (½ in.) or 6.5 mm (1/4 in.). The mechanical parts of such a device consist of a 3.66 m (12 ft) aluminum square tube mounted on two end-brackets with four screws each for level adjustment. A sliding mechanism, to which a dial indicator was attached, traverses the tube to measure surface variation and rutting. In order to obtain accurate and correct readings, the dial indicator was later replaced with a digital transducer. To eliminate human error digital data needed to be recorded electronically. For this purpose the electronic digital indicator and associated laptop computer were acquired with funds from this project.

3.0 DESCRIPTION OF THE FACILITY USED

A detailed description of the facility can be found in “Development of an Accelerated Testing Laboratory for Highway Research in Kansas [1].” This chapter presents an overview of the main features of the Kansas Accelerated Testing Lab (K-ATL) including new improvements to the equipment and additional capabilities implemented at the lab since the original report was prepared.

The K-ATL is part of a broader facility named the “Kansas State University Testing Laboratory for Civil Infrastructure.” The facility also includes the Kansas Falling Weight Deflectometer (FWD) state calibration room, and a shake-table for structural dynamic testing and earthquake engineering research. The FWD room is adjacent to the main testing lab and the shake-table is installed in an empty test pit, similar to those filled with compacted soil and used for pavement testing.

3.1 Laboratory Space and Test Pits

The laboratory area consists of about 537 m^2 (5775 sq. ft) of test space which includes the main test area of about 418 m^2 (4500 sq. ft) with the test pits at the center, about 93 m^2 (1000 sq. ft) for the FWD calibration room, and about 26 m^2 (275 sq. ft) for the electrical and mechanical rooms where the pavement cooling and heating equipment is installed.

Two 1.8 m (6 ft) deep test pits are located in the center of the lab. The main pit is 9.8 m×6.1 m×1.8 m (32'×20'×6') and has been partitioned into a 6.1 m×6.1 m×1.8 m (20'×20'×6') pit for pavement testing, and a 3.7 m×6.1 m×1.8 m (12'×20'×6') pit presently used for earthquake research.

Next to this pit is an insulated environmental pit which is 6.1 m×3.7 m×1.8 m (20'×12'×6') and which has metal (stainless steel) U-tubes buried in the soil underneath the specimen and in which a glycol solution is circulated to freeze or heat both the subgrade and the slab. Adjacent to the environmental pit is a 1.2 m (4 ft) wide access pit. It is used to allow easy access to instrumentation and heating/cooling U-tubes. It currently includes the main headers used to distribute and collect the glycol solution to and from the U-tubes. The headers have ball-valves on the supply and return sides of each U-tube.

The lab floor is 457 mm (18 in.) thick throughout the ATL area and is structurally integral with the pit walls. Floor beams are buried in the concrete floor on both sides of the pit to guide the testing frame and provide attachment (tie-down) against uplift when the load is applied to the specimens. The floor design includes provisions for confining the edges of concrete slab specimens that tend to contract when cooled in the environmental pit. This simulates the thermal tensile stresses created in a section of a continuous concrete highway where the joints would restrain the contraction in the direction parallel to the highway centerline. For these reasons, 19 mm (3/4 in.) threaded rods are used to attach the test slabs to the top of the 457 mm (18 in.)-thick vertical pit walls. The rods, embedded in the concrete slabs, pass through 25 mm (1 in.)-diameter sleeves staggered at 76 mm (3 in.) intervals.

3.2 Test Frame

The test frame is shown in Figure 3.1. The two main girders and four columns are made of W30×99 rolled beams. The frame span is 12.8 m (42 ft) center-to-center. This allows the carriage to get off the specimen before it hits the end of the track where a system of air springs redirect the carriage in the opposite direction.

The elevation at which the girders are connected to the columns was raised by 102 mm (4 in.) prior to testing an AC overlay that was placed over a previously tested PCCP section. The frame is designed such that the beam/column rigid connection can be altered at 76 mm (3 in.) vertical increments.

3.3 Wheel Load Assembly

The test frame and loading devices were designed and fabricated by Cardwell International, Ltd., of Newton, Kansas. The wheel assembly consists of a tandem axle assembly (TAM) with air suspension system (air-bags). The wheel assembly (carriage) is an actual bogie from a standard truck (see Figure 3.2). A manually controlled air-compressor provides pressure in the air-suspension system and therefore applies load to the wheel axles. The wheel load versus air pressure relation was verified for each set of wheels using a portable weigh-scale of the local Highway Patrol authority. The air-bag pressure was increased linearly at 69 kPa (10 psi) increments and the load was recorded until it reached 178 kN (40,000 lbs), including the self weight of the bogie and reaction frame.

The arrangement allows the system to load one or both axles as desired. One or more pairs of tires may be replaced by a super-single if a test requires so. Normally the system would be loading in both direction as the wheel assembly moves back and forth. However, one-way traffic simulation can be achieved through a hydraulic system that can lift the wheel axles either manually or automatically. The automatic mode will cause the eight wheels to be lifted off the ground when the carriage reaches the end of the track until it goes back to its initial position and starts a new load cycle. The manual mode is used when the whole test frame needs to be moved off the specimen or across the laboratory space. The frame is moved by pulling it using an overhead crane. Accurate positioning is achieved manually with a pry-bar.

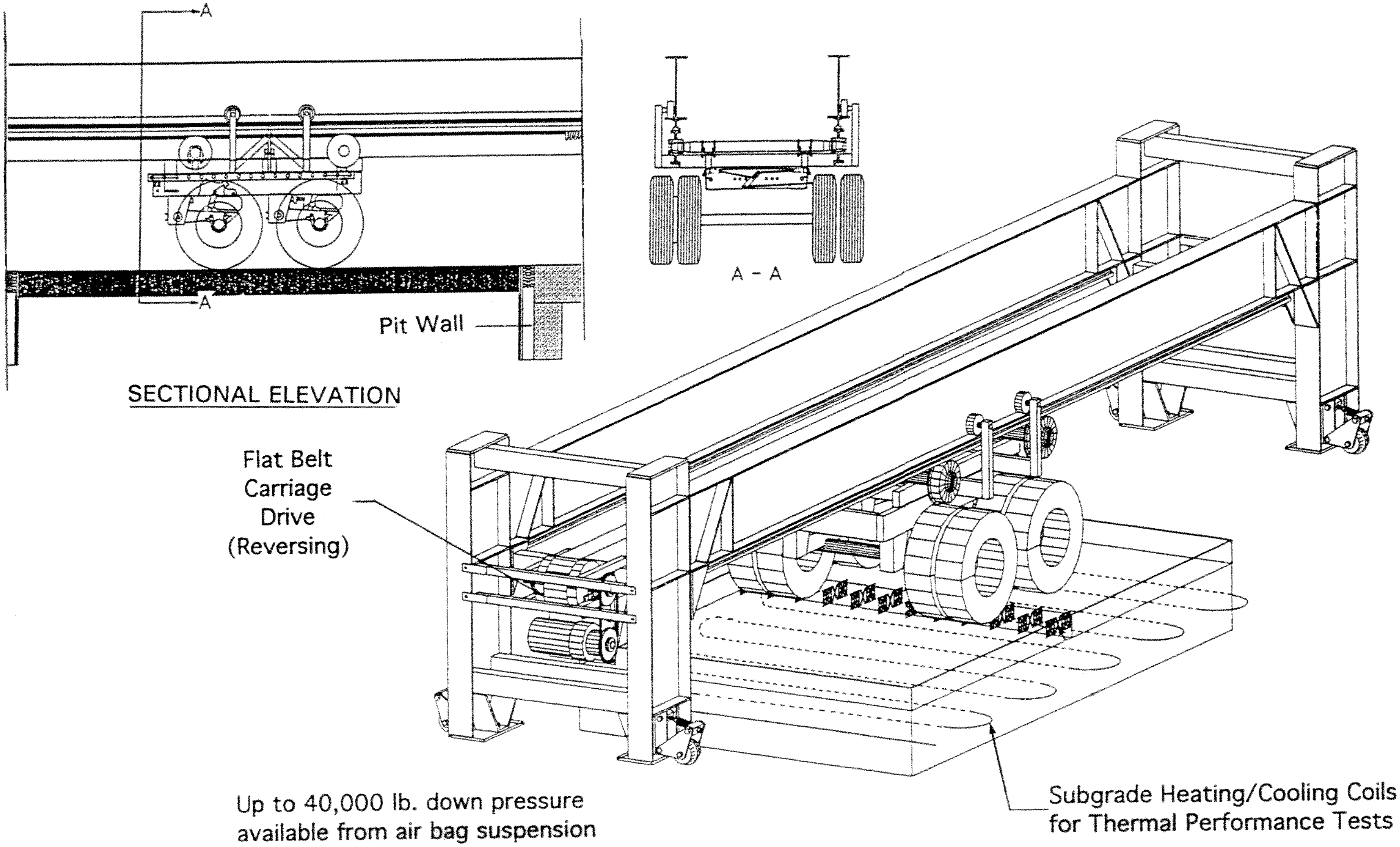

Figure 3.1 Test Frame and Wheel Load Assembly (Design by Cardwell International, Inc.)

Figure 3.2 Wheel Assembly and Tandem Axles

Figure 3.3 Wheel Assembly Completing One Repetition
(photo taken by KSU Photographic Services)

The TAM is moved back and forth along the track using a flat conveyor belt driven by a 14.9 kW (20 HP) variable speed electric motor which reverses direction every time the carriage reached one end or the other of reaction frame (Figure 3.3). The fastest safe operating speed achieved is 300 cycles per hour, or 600 load applications per hour for the two-way passage operation. At this rate, the average speed of the wheel's axles is 5.6 km/h (3.5 mph) over the total travel distance of 9.1 m (30 ft); however, the speed over at least 5.5 m (18 ft) at the middle portion of the 12.8 m (42 ft) track is about 11.3 km/h (7 mph).

3.4 Heating System--Infrared Radiant Heaters

This system is designed only for surface heating and uses infrared radiant heaters. It best simulates heating of a roadway surface by direct radiation from the sun. It consists of four lines mounted on supporting brackets parallel to the direction of the rolling of the carriage, two for each set of wheels of the axle assembly, one line on each side of a wheel path. A separate sensor and control unit is installed on each individual line to monitor/cycle its operation and maintain the desired surface temperature of the pavement. The lines radiate heat the full 6.1 m (20-ft) length of the wheel path, but only heat the width of the pavement at the wheel paths. Temperatures as high as 121°C (250°F) can be achieved, but values up to 50°C (122°F) are more realistic for highway pavement applications.

4.0 DESCRIPTION OF THE TEST EXPERIMENT

This chapter gives a detailed description of the test experiment including the hot asphalt mix types and pavement placement, loading conditions, heat application and temperature setting, sensor installation and data acquisition, and the performance monitoring plan.

4 .1 Mix Types and Pavement Construction

4.1.1 Pavement Structure

Four mixes were tested in this experiment. These are denoted as follows:

Mix 1: a standard KDOT Marshall-type mix, BM-2C (1B97016A)
Mix 2: a Superpave mix SM-2A with 20% sand (1G98006)
Mix 3: a Superpave mix SM-2A with 30% sand (1G98011)
Mix 4: a Superpave mix SM-2A with 15% sand (1G98012)

Each of these mixes was used to construct a pavement specimen. In this report--mainly for simplicity–the pavement specimens or sections are identified by their corresponding mix number: for example, test specimen #1 will be referred to as Section 1, or simply Mix 1.

Pavement specimens constructed with the first two mixes were used as control sections. These two sections were tested under the K-ATL wheel load to compare the performance of a typical Superpave mix with a conventional Marshall mix. The sections were about 1.8 m (6 ft) wide each and were placed in the north (environmental) pit of the K-ATL. The typical testing strategy in K-ATL experiments has been that pavement sections be placed side-by-side in the same test pit and tested in pairs such that each half of the load axle is rolling on one of the two adjacent sections. The third and fourth mixes were used to construct two additional sections used as the main test sections. These were about 2.4 m (8 ft) wide and were placed side-by-side in the central pit of the K-ATL. All sections were 6.1 m (20 ft) long.

The mix designs were performed by KDOT bituminous pavement engineers. Production and placement were made under KDOT supervision and Quality Control/Quality Assurance tests were performed at the contractor laboratory in Manhattan, Kansas following KDOT current special provisions for Superpave bituminous pavement construction. Mix 3 was designed to have marginal Superpave volumetric properties. Mix 4 transitioned the “restricted zone” but still satisfactorily met most of the volumetric properties. The details of the Superpave mix designs are shown in Appendix A.

The asphalt concrete placed at the K-ATL came from batches used in construction projects in Kansas. The same contractor (Shilling Construction Co.) working on the construction project was asked to bring material (trucks) to the ATL facility. The test mixes (Mix 3 and Mix 4) were used in highway construction project #70-106 K-7191-01 (on-going at the time of placement) on Interstate 70 west of Topeka (eastbound passing lane between Mile Posts 341.0 and 346.0) by Maple Hill. The first control mix (Mix 1) was used as a 60 mm (2.4 in.) base layer in that project. The second control mix (Mix 2) was used in August 1998 on K-4 in Wabaunsee County, Kansas. Both control mixes had previously been used in Kansas highway projects and their performance appeared to be satisfactory.

The location of the control and test sections and corresponding mixes are shown in Figure 4.1.

4.1.2 Subgrade Soil

The subgrade is the same silty soil originally placed in the K-ATL pits and used during past experiments. When originally placed, it was compacted to 90% of the laboratory Maximum Dry Density (MDD) and the top 46 cm (18 in.) were compacted to 95% of the MDD [1]. Density was monitored with a nuclear density gage. After several hundred load applications during previous tests, the subgrade was deemed to be even better compacted.

4.1.3 Base Layer and Compaction

All four sections were placed on a 23 cm (9 in.)-thick granular base of 19 mm (3/4 in.) nominal maximum size crushed limestone (AB-3) with about 15% passing through a No. 200 sieve. The experiments previously conducted in the middle pit (ATL-Exp #5 and #6) consisted of asphalt pavement directly on soil without any aggregate base layer [2]. Also when removing the concrete slabs of ATL-Exp #4 (the last test conducted in the north pit [2]) most of the aggregate base used for that test was lifted or disturbed. It was therefore necessary to add AB-3 to the north pit and place a new layer of AB-3 to the middle pit. The material used was analyzed at KDOT soil lab. Soil test results are given in Appendix B.

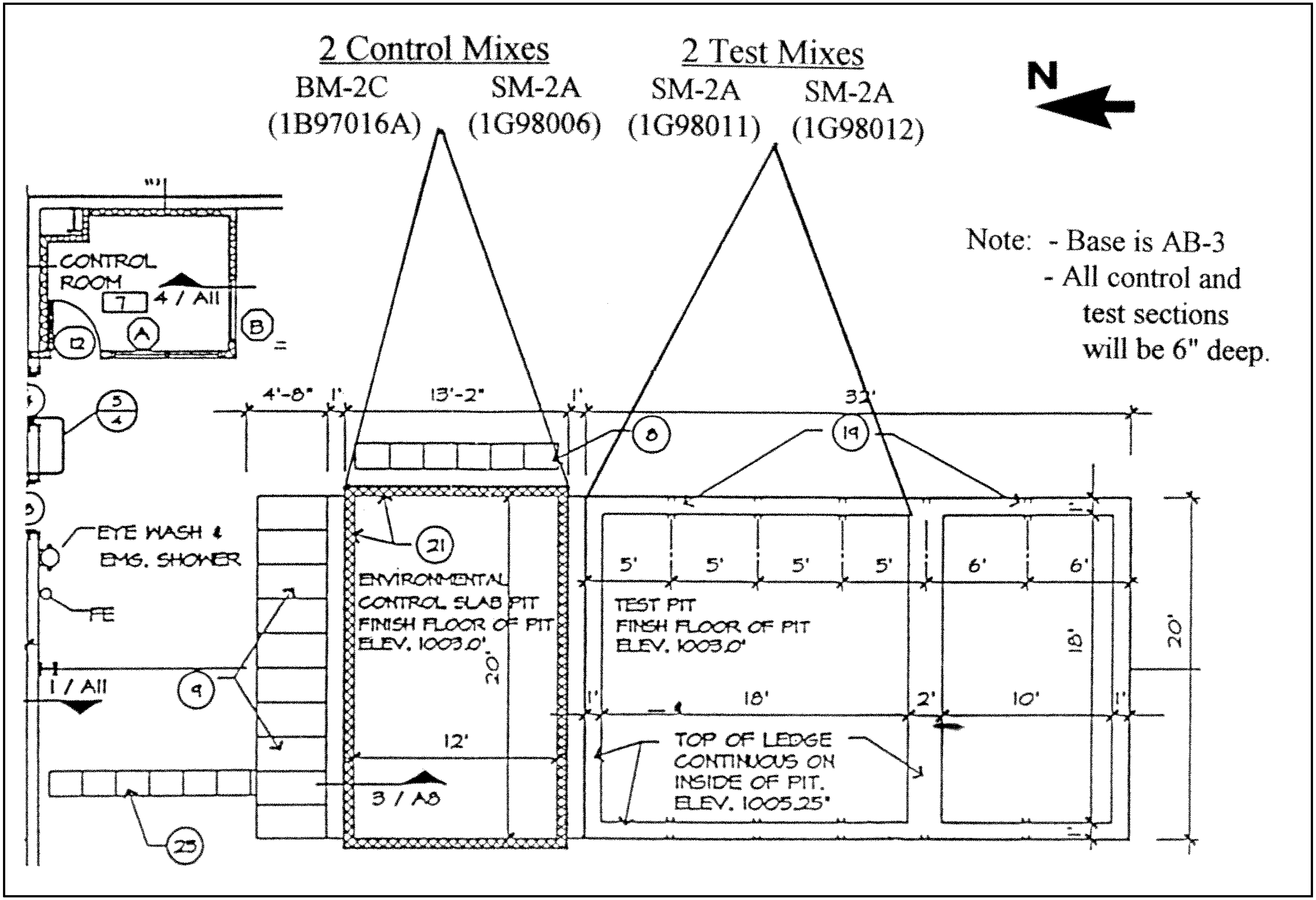

Figure 4.1 Location of Control and Test Sections at the K-ATL and Corresponding Mix Types.

Figure 4.2 Roller Soil Compaction for ATL-Exp #7

The aggregate base was compacted by a construction contractor using a baby sheep's-foot roller as shown in Figure 4.2. Compaction was verified using a nuclear density gage. Corners and edges along the pit walls were compacted using a pneumatic jumping Wacker-type plate which was also used to compact the base before the strain gages were placed. The Wacker plate compaction is shown in Figure 4.3.

4.1.4 Pavement Placement

All pavement sections were 152 mm (6 in.) thick and were placed in two lifts of about 76 mm (3 in.) each. Only the test sections (placed in the middle pit) were instrumented for strain and pressure measurements. Other monitoring tests such as rutting profiles and nuclear densities were performed on all four sections.

Figure 4.3 Plate Soil Compaction for ATL-Exp #7

The control sections were placed first, and a few weeks later the test sections were constructed. Construction took place in September and October 1998. Mix 1 was the first to become available during the corresponding field construction project and was therefore placed first in the north pit as the north lane. Then a full-depth straight cut was made longitudinally with a pavement circular saw to obtain a 1.8 m (6 ft) wide lane and make room for the second control section (Mix 2).   Figure 4.4 (photo taken facing West) shows Mix 1 in place, at the right of the picture, and the cut edge and aggregate base ready for Mix 2. Timber form-work was placed parallel to the wheel rolling direction against the long sides of the pit wall as shown at the left of the picture. Such form-work was later removed after asphalt was placed to allow for a 50 mm (2 in.) gap between the slabs and the side walls of the pit. The other three sections were placed when the corresponding mixes became available from the highway construction project. They were constructed sequentially starting with Mix 2 in the second (south) lane of the north pit, then Mix 3 as the north lane of the middle pit, and finally Mix 4 as the south lane of the middle pit.

Figure 4.4 Construction of Control Sections in the North Pit of the K-ATL

Figure 4.5 Placement of Asphalt Concrete Specimen in Middle Pit of K-ATL

Figure 4.5 shows Mix 3 being placed at its intended location (photo taken facing West). No form-work was needed for these sections since the lanes were 2.44 m (8 ft)-wide each and the width of the middle pit is 6.1 m (20 ft). Therefore the outer edges of these slabs were kept free since there was about a 0.61 m (2 ft) distance between the edges of the pavement and the side walls of the pit.

4.2 Loading Conditions

Loading consists of rolling wheel passes of a dual tandem axle of 150 kN (34 kips). The centerline of the tandem axle corresponds to the location of the line separating the two mixes placed side-by-side in each of the two pits. The experiment met the estimated maximum number of passes for both the control sections and test sections, which was 80,000 repetitions. A fixed wheel pass (zero lateral wander) was followed and two-pass cycles (two-way traffic) were applied throughout the tests. Tire pressure was 621 kPa (90 psi).

The control sections (Mixes 1 and 2) were loaded first up to about 20,000 load repetitions. Then, the test sections (Mixes 3 and 4) were loaded until that same number of cycles was applied. After that, each pair of the control sections and test sections were loaded in turn, 20,000 repetitions at a time. This loading sequence was determined in consultation with the project monitor and with the members of the Technical Committee for reasons explained below in Section 4.3.

As requested by the K-TRAN project ([3], p.7 and 14, Task 6), after the first 10,000 repetitions of the 150 kN (34 kips) K-ATL tandem axle on the test sections (Mixes 3 and 4), different axle configurations and wheel loads were applied. The following variations were applied:

1. 160 kN (36 kip) tandem axle
2. 150 kN (34 kip) tandem axle
3. 145 kN (32.5 kip) tandem axle
4. 100 kN (22 kip) single axle
5. 90 kN (20 kip) single axle
6. 80 kN (18 kip) single axle

During the application of these cycles, both strain and pressure measurements were taken simultaneously at each of the eight strain gages locations (as discussed in Section 4.4) one location at a time. At each of the gage and corresponding pressure cell locations, about 10 cycles were run first to ensure that stability of the data acquisition system is reached, then 25 additional complete cycles (50 load repetitions) were applied and digitally recorded.

This task needed about 3,400 load repetitions after which testing resumed with the normal 150 kN (34 kips) tandem axle selected to complete the 20,000 repetitions on these test sections, and all subsequent load cycles for the rest of this experiment.

4.3 Heat Application and Temperature Setting

Heat was applied to the surface of the pavement specimens using infrared radiant heaters projected towards the centerline of the wheel paths for the test sections as well as for the control sections. All heating occurred from the surface. Surface temperature values were periodically checked using a hand-held thermometer (Raytek Model ST6).

4.3.1 Heat Application Procedure

During the application of the tandem axle loads, the surface of the pavement was heated to 50°C (122°F). For the purpose of uniformity and consistency, it was desirable to have all load cycles applied under the same temperature conditions. Maintaining the surface temperature at 50°C (122°F) was easily accomplished by setting the radiant heater control units to this value. These are monitored by built-in infrared sensors reading temperature right of the pavement surface. However, it is more difficult to achieve constant subsurface temperatures. For instance, if the radiant heaters were kept on running all the time, including evenings and weekends, the temperature at the bottom of the pavement–originally at room temperature–will keep rising until it eventually (maybe after a few days) becomes almost constant throughout the entire slab depth. This would be slightly less than the surface temperature. At this stage, the subbase would be getting warmer too. Moreover, it is much more difficult to predict and monitor heat dissipation through the soil and pit walls. On the other hand, heaters must be removed to measure profiles, densities, etc.

Therefore, the operation of the radiant heaters needed to be controlled more closely such that, to the best possible extent, the temperature “gradient” between the surface and mid-depth of the pavement is maintained more-or-less constant. The first two weeks of testing were spent on experimentation with temperature application alone to study the thermal response of the slabs and heat transfer/dissipation characteristics of the pavement. This resulted in a heating/loading strategy that was followed throughout the rest of the experiment, as presented below.

4.3.2 Heating/Loading Combination

In addition to achieving consistency of the loading and environmental conditions throughout the experiment, it was also important to use the heating time efficiently so that the application of load repetitions does not get delayed because of the temperature cycling. The optimum strategy found was as follows:

1. The surface heaters are turned on using an automatic timer, around 4:00 AM and sometimes earlier (on Mondays following a weekend or after a

maintenance shutdown). The temperature controllers, regulated by surface infrared sensors, are always set to 50°C (122°F). By 8:00 AM, surface temperature would normally reach this value and load application begins.

2. Temperature is monitored through the slab thickness by reading and recording the embedded thermocouples, especially those in the middle layer. During heat and load application, temperatures are digitally recorded every 30 minutes.

3. When the temperature at mid-depth of the pavement slab reaches 39°C (102°F) the radiant heaters are turned off manually. Heat will still propagate down through the slab even when the heating source is off because the surface temperature will remain around 50°C (122°F) for a while. When the mid-depth temperature goes down to 36.5°C (98°F) the surface heaters are turned on again manually. Some judgement calls here are necessary to prevent overshooting and undershooting. In general, when load cycles are applied, mid-depth temperature is maintained around 37.75 ± 1.25°C (100°F ± 2°F) and the temperature differential between the surface and mid-depth remains no less than 11°C (20°F), otherwise the testing machine is stopped until favorable temperature gradient is restored.

4. Around 5:00 PM, the ATL testing machine will be stopped for the day. Heaters are turned off and the automatic timer is set for early morning of the next working day.

Following this strategy, 10,000 repetitions could be applied in three to four days and testing was possible any day of the week. Most importantly, load cycles were consistently applied only when the temperature differential between the surface and mid-depth is around 11°C (20°F). That ensured that loading was always under the same temperature conditions at any given time during the test.

No chiller or refrigeration was used. The only “cooling” occurred overnight or when the heat source was turned off allowing removal of heat by natural convection. The lowest temperature ever reached was the room temperature of the lab which is kept around 21°C (70°F).

4.3.3 Effect of Loading Time Sequence

In following the load/heat application described above, the following potential problem concerning the pavement behavior was raised: Posing for a few days between load/thermal applications may have an effect on the fatigue properties of the asphalt concrete pavement. Switching from one pit to the other can give the sections that are not being tested a chance to “rest” and consequently to “heal” from damage and plastic deformation caused by high temperature and load cycles. This may result in strengthening of the material that otherwise would not take place if the sections were tested continuously without rest.

This phenomenon was not to be investigated in depth during this experiment. However, consistency of the test/rest sequence and the load/heat application procedure can ensure that all sections are treated the same. For this reason when the facility was closed during the University winter break all sections had reached exactly 20,000 load repetitions. On the other hand, sections tested side-by-side in the same pit have been exposed to the same conditions and therefore, for the purpose of comparison, "resting/healing" will not be considered a parameter.

4.4 Sensor Installation and Data Acquisition

Several sensors were placed in the test sections to monitor pavement behavior. In addition to measurements obtained from these sensors, FWD tests were conducted at the beginning of the experiment, and nuclear density measurements and surface profiles were recorded periodically.

4.4.1 Instrumentation and Sensor Placement

To compare the performance of the different pavement slabs the following instrumentation was used (in the *test sections* only):

1. Dynamic Soil Pressure Cells (Geokon 3500),
2. Strain Gauges (Dynatest PAST-2AC), and
3. Thermocouples (fabricated in-house at the K-ATL).

These particular types of sensors were successfully used at the K-ATL in previous projects and have shown good performance and acceptable results [2]. In particular, data from similar Geokon pressure cells and Dynatest strain gauges (same models) were measured and digitally recorded by the K-ATL personnel during the FY-98 Accelerated Testing project (ATL-Exp #5 and 6). Also, thermocouple data were read and digitally recorded during FY-97 project (ATL-Exp #3 and 4).

As in the case of the previous experiments, these sensors were installed according to the manufacturer's guidelines and following procedures recommended by the MnRoad research program [6,7]. Response traces similar to those reported by other experimental researchers [8,9] and shown in Figures 2.8 and 2.9 were obtained at the K-ATL.

The layout and location of the different sensors on the plan of the *test sections* and through the depth are shown in Figure 4.6.